TM-100
0106

200 BeV STORAGE RING PARAMETERS

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For the purpose of making cost comparisons we will give here a set of design parameters for a 200 BeV storage ring using iron-core magnets and having approximately the same features and performance as those of the 100 BeV storage ring given in TM-55. Similar to the 100 BeV ring, we choose here a separated function FODO lattice with six matched insertions. The same field intensity of about 20 kG and field gradient of about 250 kG/m are chosen for the bending and focusing magnets.

<u>Scaling</u>

1. With the field intensity held invariant the total length of bending magnets $L_M \propto p$. For minimum betatron-oscillation excursion the quadrupole strength is given by $\frac{B'\ell_Q}{B\rho} \propto \frac{1}{\ell_c}$ or $\ell_Q \propto \frac{B\rho}{B'\ell_c} \propto \frac{p}{\ell_c}$ where ℓ_Q = quadrupole length, ℓ_c = cell length, and B' is assumed to be invariant. The total length of quadrupoles is, therefore, $L_Q = N_c \ell_Q \propto \frac{R}{\ell_c}\frac{p}{\ell_c} \propto \left(\frac{p}{\ell_c}\right)^2$ assuming as a first approximation $R \propto \rho \propto p$. To obtain the same scaling for the total length of quadrupoles as for that of bending magnets we must have $\ell_c \propto \sqrt{p}$. Thus, $L_Q \propto L_M \propto p$.

2. The above scaling of cell length ℓ_c gives immediately $\beta \propto \ell_c \propto \sqrt{p}$, $x_p \propto \ell_c \theta_c \propto \frac{\ell_c}{N_c} \propto \frac{\ell_c^2}{p} \propto 1$.

3. The single beam space charge detuning which, in our case, limits the beam intensity is given by

$$\Delta\nu = \frac{Nr_pR}{\pi\gamma\nu h^2}\left(\varepsilon_1 + \frac{h^2}{g^2}\varepsilon_2\right) \approx \frac{Nr_pR}{\pi\gamma\nu h^2}\varepsilon_1$$

since ε_2 is negligibly small. Solving for N we get

$$N = \left(\frac{\pi\Delta\nu}{r_p\varepsilon_1}\right)\frac{\gamma\nu h^2}{R} \propto \frac{\gamma\nu h^2}{R} \propto h^2\sqrt{p}$$

and

$$I \equiv \frac{N}{2\pi R} \propto \frac{h^2}{\sqrt{p}}$$

where we have taken as a good approximation $\gamma \propto p$ over the energy range of interest.

The luminosity is given by

$$L = \frac{cI^2}{\alpha b} \propto \frac{1}{\alpha}\sqrt{\frac{p}{\beta}}\,\frac{h^4}{p} \propto \frac{1}{\alpha}\,\frac{h^4}{p^{3/4}} .$$

Because of the high power of h to make L non-scaling h cannot have a strong dependence on p. Therefore, we might as well make $h \propto 1$. The vertex angle of the production cone of secondary particles scales as $\frac{1}{p}$; therefore, the beam intersecting angle α could decrease with increasing p at a rate not faster than $\frac{1}{p}$. We will take $\alpha \propto p^{-3/4}$. Together with $h \propto 1$ this gives $L \propto 1$, as desired. It gives further $N \propto \sqrt{p}$ and $I \propto \frac{1}{\sqrt{p}}$.

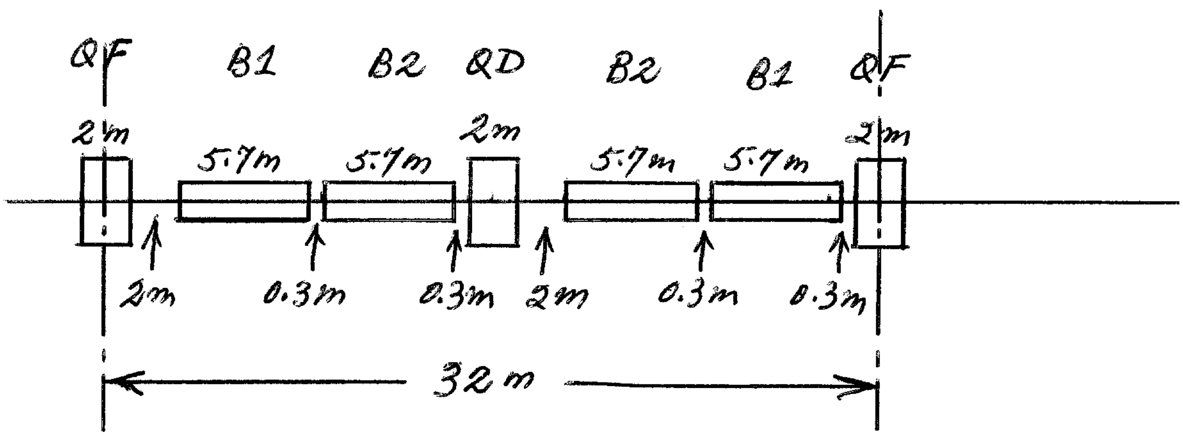
Lattice

1. The same lattice and insertion structures as in the 100 BeV ring are used here. Three of the six beam crossing insertions symmetrically located are matched to give $x_p = x_p' = 0$ and low β_y at the beam crossing point, and are used for experi-

mentation (E insertions). The remaining three (I insertions) are matched to give large x_p and β_x in the central long drift space; two of these will be used for injection and beam dump and the third will be reserved for future use for doing experiments. The I insertions are symmetric with reflection symmetry about the midpoint, whereas because of the requirement that β_y be lowest at the asymmetrically located crossing point, the E insertion is intrinsically asymmetric.

2. Based on the scaling laws set down above and with a certain amount of cut-and-fit we arrive at the following lattice parameters:

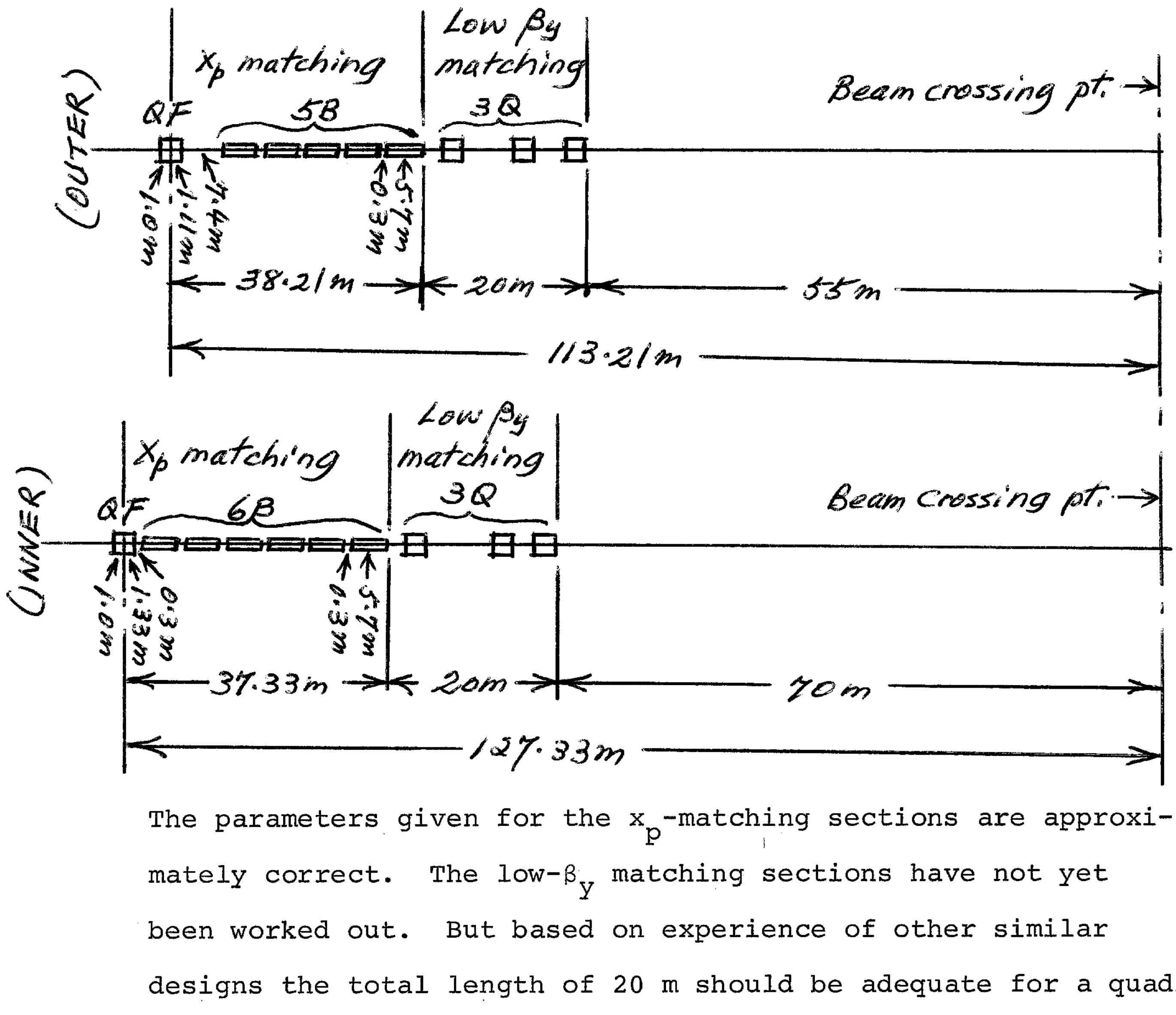
A. A normal cell is shown below:



$$
\left\{
\begin{aligned}
\theta_M &= \frac{2\pi}{369} = 0.01703 \text{ rad} = 0.9756^\circ \quad (N_M = 369) \\
B_M &= 20.02 \text{ kG } (B\rho = 6702 \text{ kGm}, \ \rho = 334.8 \text{ m}) \\
\ell_M &= 5.7 \text{ m} \\
B'_Q &= 259.7 \text{ kG/m} \\
\ell_Q &= 2 \text{ m}
\end{aligned}
\right.
$$

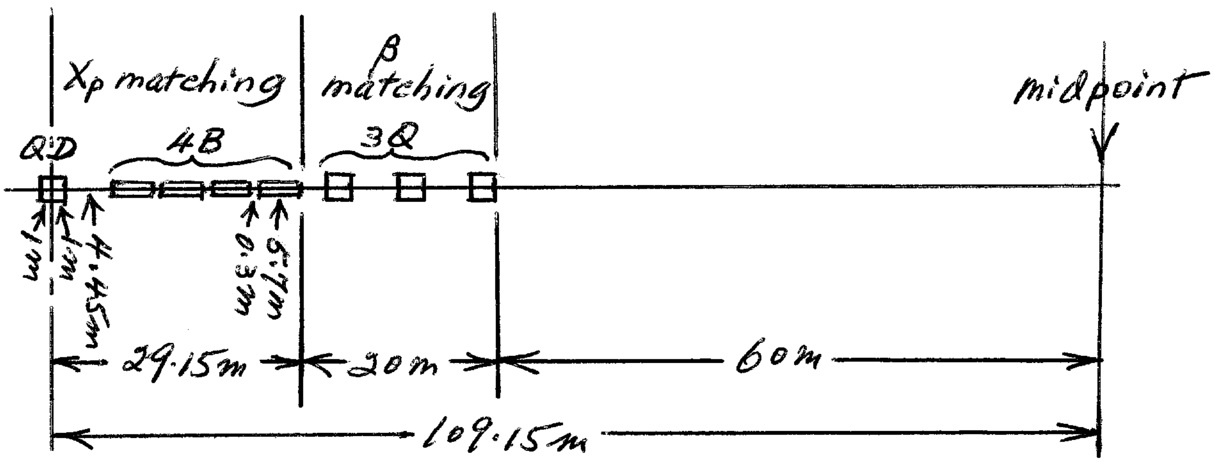
$$\left\{\begin{array}{l} \beta_{max} = 52.7\ \text{m} \\ \beta_{min} = 13.7\ \text{m} \\ x_{p\ max} = 1.99\ \text{m} \\ x_{p\ min} = 1.09\ \text{m} \end{array}\right.$$

B. An E insertion is as follows:



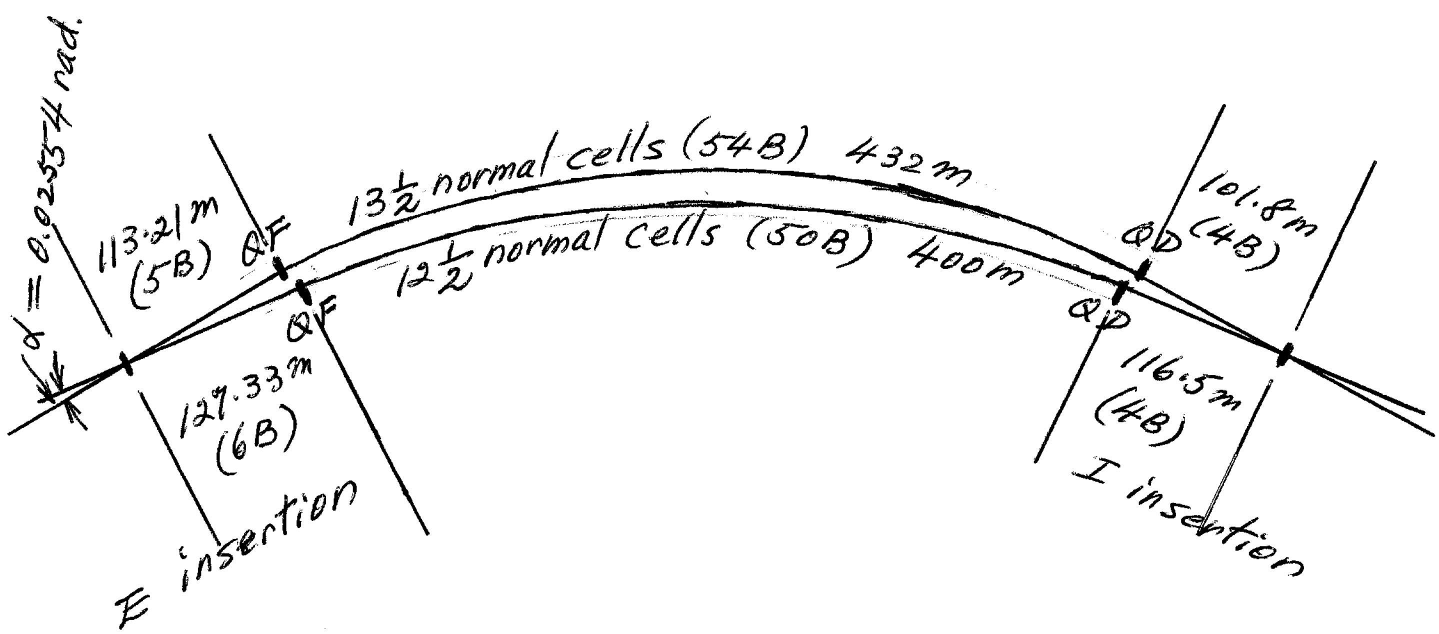
The parameters given for the x_p-matching sections are approximately correct. The low-β_y matching sections have not yet been worked out. But based on experience of other similar designs the total length of 20 m should be adequate for a quadrupole triplet or quadruplet to produce a low β_y at the beam crossing point.

C. An I insertion is shown below:



Since the I insertion is symmetric the inner and outer halves are identical. Notice that the reference point is now the mid-point instead of the beam crossing point.

D. A sextant now looks like:



The total circumference is, therefore,

$$3 \times \left[(113.21+432+101.8)+(127.33+400+116.5)\right] = 3872.52 \text{ m}$$

and the radius is $R = \frac{3872.52}{2\pi}$ m = 616.33 m. The outer arc contains 5+54+4 = 63 bending magnets and the inner arc contains 6+50+4 = 60 bending magnets. The intersecting angle α is, therefore, given by $\alpha = \frac{1}{2}(3\theta_M) = 0.02554$ rad $= 1.4634^\circ$. The separation between beams at the ends of the long drift length in the middle of an E insertion is approximately 70x.02554 = 1.79 m.

<u>Injection and RF</u>

1. One turn injection will be used. A fraction $\frac{R}{1000 \text{ m}}$ = 0.61633 of a main ring turn is injected into the storage ring to fill a complete turn of the storage ring, and the remaining fraction of the main ring turn is extracted into the external proton beam for regular experiments in the accelerator experimental areas. The beam to be injected will be channeled through a series of septum magnets into the storage ring at a very small angle from the injection orbit. At the point where the beam crosses the injection orbit the beam is bent to follow along the injection orbit by a partial aperture kicker magnet which is screened from affecting the stacked beam. After the full turn is injected the kicker screen is mechanically retracted and the beam is decelerated by the RF to the beam stack.

2. The main ring RF harmonic number is 1113. Therefore, the storage ring RF harmonic number is 1113 x 0.61633 = 685.975, which means that the injection orbit should have a harmonic number of exactly 686 and a radius of $\frac{686}{1113}$ = 616.3522 m.

Aperture and Luminosity

1. The vertical aperture has been assumed to be identical to that of the 100 BeV storage ring, namely 1.0 inch for B1 and 1.25 inch for B2. The contribution to ν from the 6 x 13 = 78 normal cells is about 15.6 and the contribution from all the insertions is about 6.0. Therefore the betatron oscillation wave number is approximately ν = 21.75. The single beam space charge limit is therefore,

$$N = \left(\frac{\pi\Delta\nu}{r_p \varepsilon_1}\right) \frac{\gamma\nu h^2}{R} = 4.87 \times 10^{15}$$

With the same degree of conservatism as for the 100 BeV ring we shall assume a design intensity of 1.8×10^{15}. Since from each main ring pulse we get approximately $0.6 \times 5 \times 10^{13} = 3 \times 10^{13}$ protons, 60 main ring pulses are needed to stack a beam of 1.8×10^{15} protons. At the main ring rep-rate of 20 pulses/min it will take 6 min to fill both rings.

2. The emittances of the injected beam at 200 BeV, including a dilution factor of 2 in the beam transport, are

$$\begin{cases} E_x = 0.46\pi \text{ mm-mrad} \\ E_y = 0.18\pi \text{ mm-mrad} \end{cases}$$

For the 100 BeV storage ring a β_y as low as 4 m had been obtained at the experimental beam crossing point. We can, therefore, safely assume that a low β_y of $4\sqrt{2}$ = 5.7 m can be attained for the 200 BeV storage ring. This gives a half vertical beam height at the crossing point of

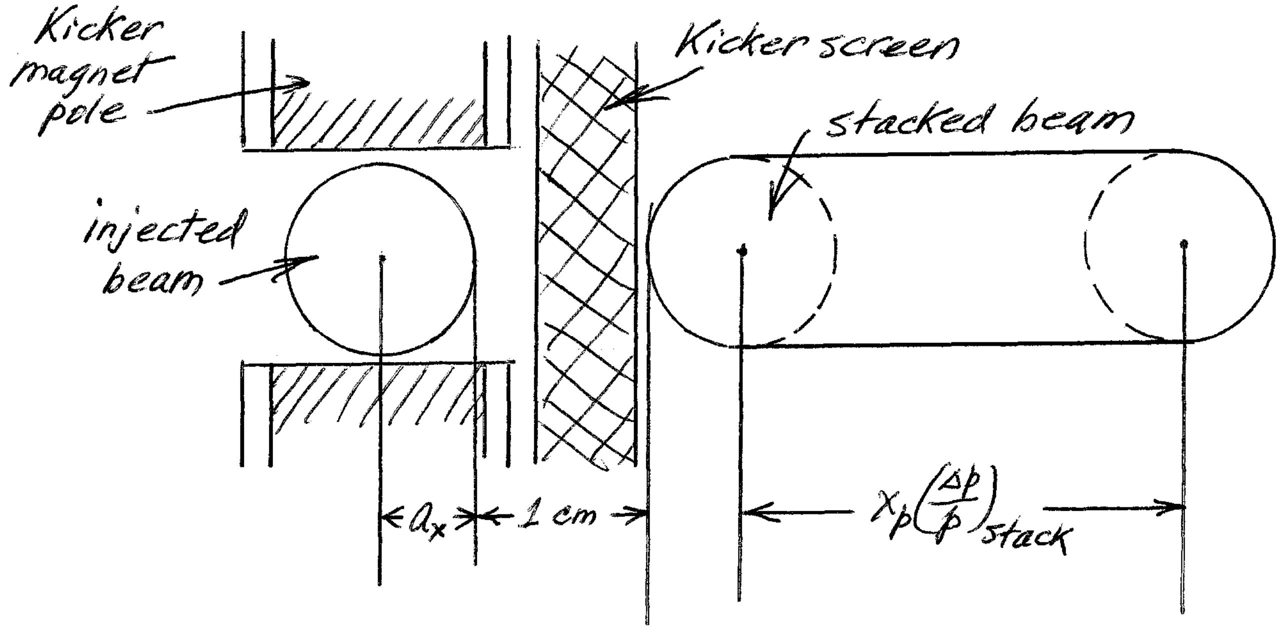
$$b = \sqrt{0.18 \times 5.7} = 1.01 \text{ mm}$$

and a luminosity of

$$L = \frac{c}{\alpha b}\left(\frac{N}{2\pi R}\right)^2 = 2.6 \times 10^{32} \mathrm{cm}^{-2}\mathrm{sec}^{-1}.$$

3. The momentum spread of the injected beam at 200 BeV including a dilution factor of 8 and after debunching is $\frac{\Delta p}{p} = \pm 0.2 \times 10^{-4}$. In the 60 turn stack the momentum spread is, therefore, $\left(\frac{\Delta p}{p}\right)_{\mathrm{stack}} = (\pm 0.2 \times 10^{-4}) \times 60/(\text{stacking efficiency})$. Taking a conservative stacking efficiency of 60% we get $\left(\frac{\Delta p}{p}\right)_{\mathrm{stack}} = \pm\ 2 \times 10^{-3}$.

Because of the large number (60) of main ring pulses to be injected we will use a partial aperture kicker magnet which bends only the injected beam and which is screened from the stacked beam. The space between the injected and the stacked beams required for the screen is about 1.0 cm at the kicker where x_p is assumed to be a maximum. This is shown in the following phase diagram.



Assuming normal field and alignment errors, the closed-orbit distortion amounts to about $3\sqrt{\beta_x(m)}$ mm.

To reduce sagitta we assume that the 5.7 m long bending magnet is constructed in two straight sections each 2.85 m long. The horizontal aperture requirements are, then

	B1	B2
β_x	49.2 m	29.0 m
x_p	1.92 m	1.50 m
$4a_x$	4x4.76 mm	4x3.65 mm
kicker screen space	9.66 mm	7.54 mm
$x_p(\frac{\Delta p}{p})_{stack}$	7.68 mm	6.00 mm
closed-orbit distortion	21.04 mm	16.16 mm
sagitta	3.03 mm	3.03 mm
Total	60.45 mm (2.38 inch)	47.33 mm (1.86 inch)

With rounding off one sees that the apertures for the 100 BeV storage ring, namely

$1.0\text{x}2.5$ inch^2 for B1, $1.25\text{x}2.0$ inch^2 for B2

are still appropriate for the 200 BeV ring.